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EVALUATION OF THE DEGREE OF DIFFUSENESS IN REVERBERTAION CHAMBERS BY SPATIAL CORRELATION TECHNIQUES

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ABSTRACT. Reverberation chambers used for many important acoustical measurements should have three dimensional diffuse sound fields. In this paper, a new method based on spatial correlation techniques to evaluate the degree of diffuseness of the sound field in a reverberation chamber is described. It is well known that the spatial correlation coefficient R for the sound pressure at two points in a three dimensional diffuse sound field is sin kr/kr, where r is the distance between the two points and k is the wave number. However, sin kr/kr, which is obtained in only one direction, is a necessary but not sufficient condition for a completely diffuse sound field.

In order to correct this defect, we took note of the directional distribution of correlation coefficients and suggested that it was important to observe the correlation coefficients for all directions in the field. To simplify the procedure, a value R_π was provided, which is a correlation coefficient at kr = π (i.e., r = λ/2), and the directional distribution of R_π was measured by keeping the distance of both microphones at λ/2. The three dimensionally measured R_π was entered on split spherical surfaces, and its distribution pattern was expressed like a contour map.

Many distribution patterns were made for various sound field conditions in two

reverberation chambers (No. 1 513 m^3, non-parallel walls and No. 2 120 m^3, parallelepiped). From the experimental results above, we have concluded that the distribution pattern was closely related to the condition of the sound fields. An especially close correlation was observed between diffuseness of the sound field and the area $|R_\pi| \leqq 0.1$ of the distribution pattern. Therefore, to judge diffuseness it is sufficient to consider only the area $|R_\pi| \leqq 0.1$, and the diffusivity index D_π, which was defined as follows: D_π = (area $|R_\pi| \leqq 0.1$)/(all spherical surface area) × 100 (%). If D_π = 100%, the sound field is judged as three dimensionally diffuse. The experimental values D_π obtained for the two reverberation chambers extended from 20% ∿ 100%.

The dependence of measured reverberant absorption coefficients of the material on the diffusitivity index D_π were investigated, and a close dependence was observed between them.

For the reverberation chamber in which D_π is greater than 70%, it could be judged that its sound field would fulfil the requisite for the diffuse sound field, this being the premise of the reverberation chamber method.

This evaluation method has many advantages; 1) the structure of sound field is made clear at the same time; 2) the applicable frequency range has no restriction in principle; 3) it is not necessary to fear the influence of microphones and ancillary equipment on the sound field, because that apparatus is small. This method becomes especially useful in the low frequency range, which has not yet been solved.

This evaluation method will be a great help in attacking the problem of diffuseness of the sound field in a reverberation chamber.

Foreword

Reverberation chambers, for which the sound field must be three-dimensionally diffuse, are used in a large number of important acoustical measurements, such as measurement of the acoustic absorptivity of sound absorbing materials, the acoustic output of noise sources, and the transmission loss in acoustic insulating materials. In these measurements, the most important precondition is that the sound field in a reverberation chamber must satisfy the conditions of a diffuse sound field. /133*

In other words, the diffuse sound field is defined by assuming the following two conditions concerning the sound field:

1) The energy density of the sound must be uniformly distributed in all places in the chamber.

2) The movement of the sound energy in all places in the chamber must be uniform in all directions.

However, in actual reverberation chambers it is extremely difficult to make these conditions apply in the strict sense, and in many cases a yardstick is required by which one can indicate and evaluate the degree of diffuseness for actual approximately diffuse sound fields.

In the past, the following methods were generally adopted in evaluating the degree of diffuseness of the sound fields in reverberation chambers:

1) Departure of the attenuation curve from exponential-function attenuation;

*Numbers in the margin indicate pagination in the original foreign text.

2) Dispersion of the reverberation times measured repeatedly under identical conditions; or

3) Dispersion of the reverberation times based on the position of microphones, speakers, and sound absorbing materials.

In each of these methods, there still remain a number of difficulties in deriving a degree of diffuseness which can be quantified as an index.

Recently, Nagata and Matsumoto have reported on a method of evaluation using the elevation diffuseness in the reverberation process; this method is a further development of the so-called directive diffuseness of Jusofie. They give an evaluated quantity of the degree of diffuseness which has an almost categorical relationship with the measured value of the acoustic absorptivity [1]. Nevertheless, since a directional microphone is used in this method, in relation with the directive performance there still remain problems concerning applications to the low sound range.

In this connection, the writers conceived a method based on the directional orientation of the spatial correlation coefficient.

Cook and Dammig established that in a three-dimensional diffuse sound field the spatial correlation coefficient is sin kr/kr [2, 3]. They adopted a method of evaluating the degree of diffuseness from the departures from sin kr/kr of the spatial correlation coefficients actually measured in the sound field in a reverberation chamber. The writers, believing that the spatial correlation technique is an extremely effective method for obtaining a structural grasp of a sound field, found that the direction of the straight line connecting two microphones for seeking the correlation is an important element for this purpose.

Carrying this further, they discovered the index for evaluating the degree of diffuseness of a sound field in a reverberation chamber. They also applied this method in evaluating the degree of diffuseness in irregularly shaped reverberation chambers and rectangular parallelepiped reverberation chambers when the sound field conditions were changed by means of the diffusion boards and the sound absorbing materials. They also studied the relationship between this index and the acoustic absorptivity of a reverberation chamber as found from the reverberation times measured under various diffusion conditions.

1. Spatial Correlation Coefficients in Sound Fields in Reverberation Chambers

It was established by Cook that, if a sound field is three dimensionally diffuse, the spatial correlation coefficient between the sound pressures at two points in the sound field is given by sin kr/kr. Here, k is the wavelength constant, and r is the distance between the two points. The examples in Figure 1 are the spatial correlation coefficients when sound fields were excited by means of 1/3 octave band noise at 250 Hz and 1,000 Hz, measured in the empty room state in reverberation chamber /134
No. 1 at the Kobayashi Institute of Physical Research. It was confirmed that the values of the correlation coefficients obtained under such sound field conditions, where it is assumed that the degree of diffuseness is quite good, correspond perfectly with the theoretical values.

However, when the diffuseness of the sound field was lowered by arranging large numbers of sound absorbing materials in this reverberation chamber, the measured values deviated greatly from the curve sin kr/kr, as is clear in Figure 2. These deviations could also be seen in t rectangular parallelepiped reverberation chamber, in which it is difficult to realize a diffuse sound field.

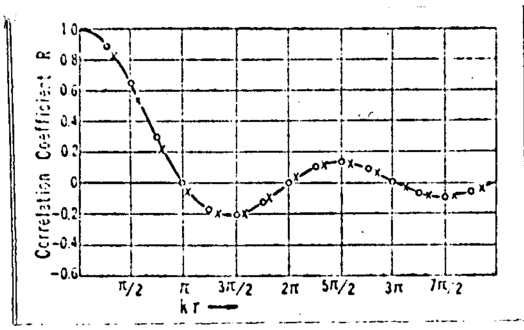


Figure 1. Spatial correlation coefficients for 250 Hz (O) and 1000 Hz (×) 1/3 octave band noise measured at the reverberation chamber No. 1 under empty room condition. Solid curve is theoretical (sin kr/kr)

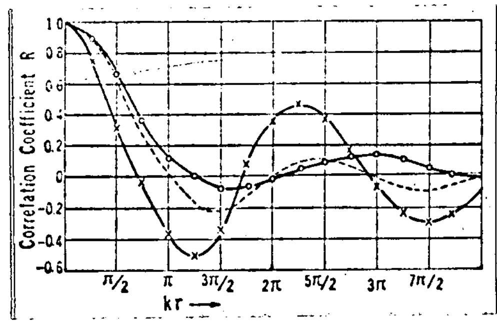


Figure 2. Spatial correlation coefficients for 250 Hz (—O—) and 1000 Hz (—×—) 1/3 octave band noise measured at the reverberation chamber No. 1 with absorbing material (area 36 m^2). Dotted curve is theoretical (sin kr/kr)

As a general tendency, these deviations grow larger as the diffuseness of the sound field declines. However, the important element here is that the direction of the straight line connecting the two points plays an important role in the deviations of the correlation curve.

On the other hand, taking r in one direction, even though the observed correlation coefficient was sin kr/kr, it is impossible to conclude that the sound field in question is three-dimensionally diffuse. For example, when there is incident sound entering at random towards the two points from the entire space, the coefficient will be sin kr/kr; even though the incident sound comes from an octant sphere, sin kr/kr will still apply [3]. That is, even though sin kr/kr in one direction alone is a necessary condition for a diffuse sound field, it is not a sufficient condition.

Thus, as for the purpose of determining a sound field by the spatial correlation technique, one cannot obtain sufficient data by measuring the correlation curve only in one direction, and it is necessary to make measurements in numerous directions. In order to study this matter, the correlator for sound field measurements described below was produced and the measurements made.

2. Correlator for Sound Field Measurements Used in Experiments

According to the equation defining the correlation coefficient, the correlator is used for calculating the correlation coefficient between two signals. Its composition is divided up chiefly into the calculating unit for the correlation coefficient and the microphone-moving unit. By simple manipulations, it is possible to seek the correlation coefficient between the sound pressures at two points.

2.1. Calculating Unit for the Correlation Coefficient

When two signals have been given to the input in the calculating unit, the correlation coefficient between the signals is calculated by the sum and difference method, and the value is indicated on the meter. A circuit block diagram of the calculating unit is shown in Figure 3.

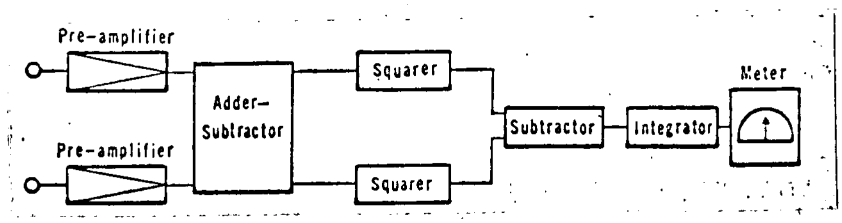


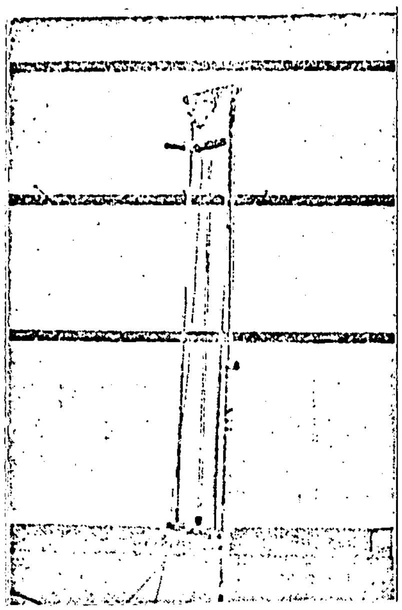
Figure 3. Circuit block diagram of the correlator

The given signals are converted into the prescribed voltage signals (u_1, u_2) by the attenuators attached to each of the preamplifiers, and these signals are sent into the adder-subtractor, where first of all the sum of these voltage signals ($u_1 + u_2$) and the difference between them ($u_1 - u_2$) are prepared. Then the squares of each, $(u_1 + u_2)^2$ and $(u_1 - u_2)^2$, are cal- /315 culated by the squarers, and calculations are performed to seek the product ($u_1 u_2$) from the difference. The calculated product is subjected to time averaging by the R – C integrator, and this value is then indicated on the meter as the correlation coefficient. The indicating meter is a zero-centered voltmeter. As for the correlation coefficient R, since $|R| \leq 1.0$, it is adjusted at full scale $R = \pm 1.0$.

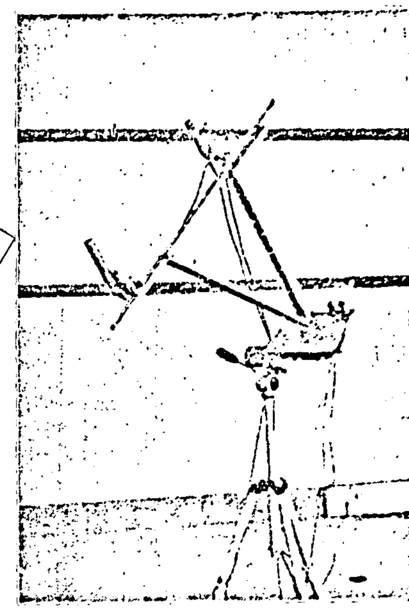
The applicable frequency range of the calculating unit is 100 - 5,000 Hz.

2.2. Microphone-Moving Unit

Two simple microphone-moving devices were produced for the purpose of carrying out sound field analysis by means of the spatial correlation coefficients. The external appearance of the equipment is shown in Figure 4.



(A) A microphone slides back and forth along two guide rails at will against the microphone fixed at an end of the rails



(B) A microphone turns with constant radius in an arbitrary plane around the fixed microphone

Figure 4. Microphone movements

Microphone-moving device A gives any desired microphone distance in one direction. While one microphone remains fixed on one end of the guide rails, the other microphone is moved backwards and forwards along the guide rails by a small-size motor and chains. It is controlled from a position far enough away from the sound field or from an isolated place; in this way it is possible to detect the distance between the microphones r. If the guide rails are fastened in the desired direction in the sound field, it is possible to measure easily the spatial correlation coefficient in this direction.

Microphone-moving device B is a device in which the fixed microphone remains in the center, and the other microphone is moved in any direction in a definite plane, maintaining a definite distance from the first microphone. Since the measuring surface can be set at will, it is possible to use this to measure the correlation coefficient of the sound pressures at a point in the sound field and any other point on a spherical surface centering in the first point. The moving microphone is semi-fixed in place on an arm bracket. It can be fixed at a suitable position, and the desired microphone distance r can be given at will.

The microphones are cylindrical dynamic microphones (Sanken Model MS-7) measuring 25 mm in diameter and 125 mm in full length. Two microphones with almost exactly the same performance properties were used. Since it was assumed that the acoustic center is located on the microphone axis, by controlling their movements so that the axes of both microphones were kept in parallel, it was possible to make the distance between the two points in question, r, coincide with the distance between the microphone axes. This was confirmed experimentally by pure sounds in an anechoic room.

However, at frequencies above 4,000 Hz, divergences were observed between r and the axial distance within the range where the microphone axial distance was smaller than the half wave- /136
length $\lambda/2$. It was assumed that this was caused chiefly by the size of the microphones. As for the signals above 4,000 Hz, since differences occurred in the phase characteristics of the two microphones, it was impossible to find the correlation coefficient between the sound pressures at two points at the same moment.

In view of the preceding, in carrying out these experiments it was assumed that the upper limit of the applicable frequency range of this correlator was 4,000 Hz.

3. Directivity of the Spatial Correlation Coefficients — Methods of Measuring and Indicating Them

Experiments were performed in a sound field in a rectangular parallelepiped reverberation chamber in order to analyze the influence of the directivity of the spatial correlation coefficients on the determination of the sound field construction.

The reverberation chamber was a rectangular parallelepiped room (No. 2 reverberation chamber, Kobayashi Institute of Physical Research) measuring 6 m × 4 m × 5 m. Microphone-moving device A was used to measure the spatial correlation coefficient in the long axis and short axis directions of the rectangular parallelepipid chamber; the results are shown in Figure 5. The dotted curve in the figure is the spatial correlation coefficient $R = \sin kr/kr$ of the three-dimensional diffuse sound field. One-third octave band noise was used to excite the sound field. The results at central frequencies of 250 Hz and 1,000 Hz were used as examples of measurements in the low sound zone and high sound zone, respectively. The measuring conditions are as shown in Figure 6. The fixed microphone was installed in the center of the room, with the sound source speaker installed in a corner of the room, with its axis following the long axis direction of the room. The room was empty.

It is obvious in Figure 5 that the two correlation curves measured in the figures are clearly different. That is, in the long axis direction there are pronounced ups and downs, while in the short axis direction the ups and downs are small. From the correlation curves obtained for these two directions, it was possible to assume that in this sound field a pronounced axial mode exists in the long axis direction.

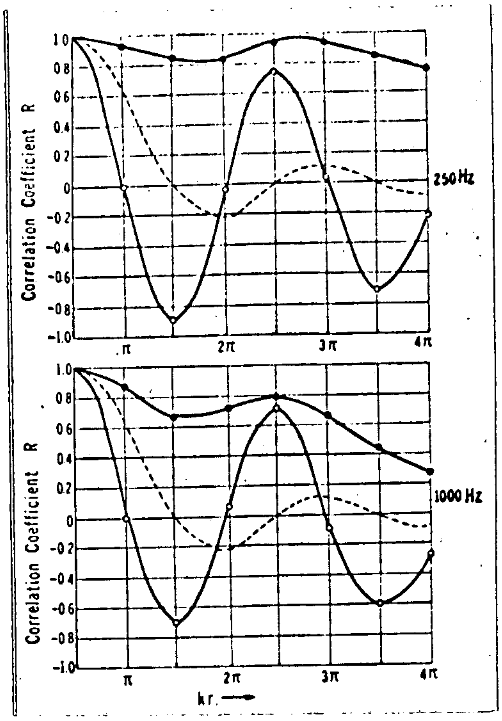


Figure 5. Spatial correlation coefficients for 250 Hz and 1000 Hz 1/3 octave band noise in the direction of long (O) and short (⊙) axis of the chamber No. 2 (as in Figure 8) under empty room condition. Dotted curve is theoretical (sin kr/kr)

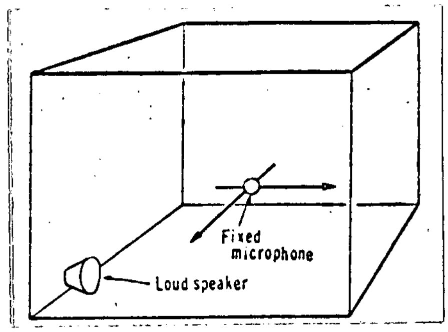


Figure 6. Measuring condition in the chamber No. 2

In this case the room was a rectangular parallelepiped chamber, and the axis of the sound source speaker was parallel to the long axis of the room. Since these conditions were relatively simple, from the measurements conducted in these two directions of the room's long and short axes, it was possible to obtain sufficient data for determining the sound field. However, in a sound field it is usually necessary to measure the correlation curves in many more directions. However, considerable trouble must be taken when one actually measures the correlation curves in numerous directions, and the efficiency is not very good. For this reason, it was decided to use the index R_{π}, defined below, to simplify the measuring procedure. Use of this index also made it possible to quantify numerically the state of the correlation curves and to simplify their handling.

R_π = [value of the correlation coefficient R at $kr = \pi$]

The statement $|R_\pi| \leqq 1.0$ always applies to R_π under this definition, and $R_\pi = 0$ in a three-dimensional diffuse sound field.

Figure 7 shows the relationship between R_π and the correlation curves obtained in a rectangular parallelepiped chamber. The data signify that, when R_π has a value close to +1, the correlation curve will have small ups and downs, and that when the value is close to −1 the correlation curve will have large ups and downs.

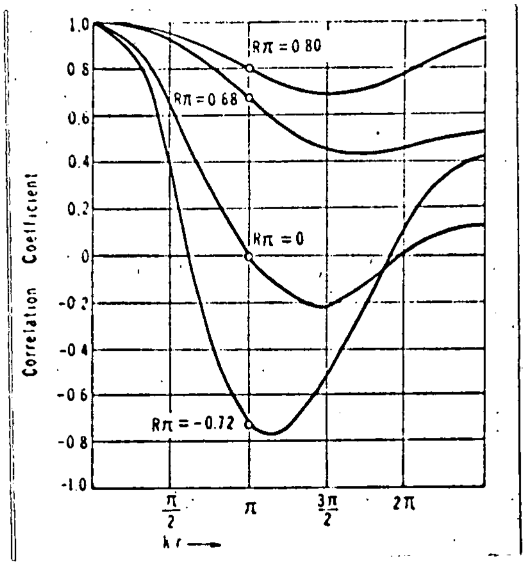


Figure 7. An example of relation between R_π (R at $k_r = \pi$) and spatial correlation curve measured in chamber No. 2

However, it is impossible to obtain, by means of R_π, data concerning the shape of the correlation curve when $kr > \pi$. There still remain, therefore, difficulties with this point. Nevertheless, this method, aimed at the range where $kr \leqq \pi$, can be put into use extensively in determining sound fields of this type. /137

Another attempt to quantify the state of the correlation curves was made by Kuttruff, who uses the value of kr at which R = 0.5 [5]. However, this method cannot necessarily be considered appropriate, since there are always cases where R > 0.5 on account of the sound field conditions and the measuring conditions.

In order to obtain the R_π actually for many directions, the microphone-moving device B was set so that there would be a distance of $r = \pi/k = \lambda/2$ between the central fixed microphone and the moving microphone. When this has been done, one need only administer any angle of rotation and carry out repeated measurements. Figure 8 shows the directional distribution of R_π actually obtained in a rectangular parallelepiped reverberation chamber. The values of R_π were inscribed in the position corresponding to the measuring directions on the spherical surface centering in the fixed microphone.

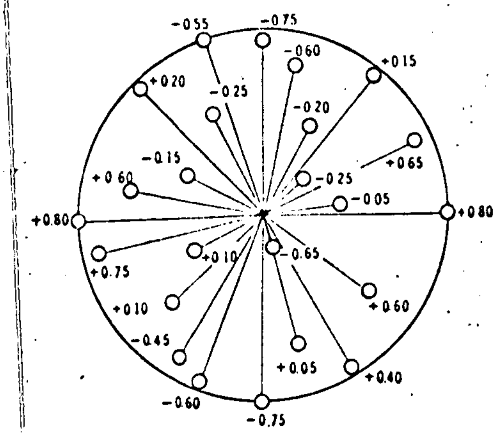


Figure 8. An example of directional distribution of R_π in the chamber No. 2

4. Diffuseness of Sound Field Inside Reverberation Chamber and Directional Distribution of R_π — Calculation of Diffusivity Index D_π

The state of three-dimensional distribution of the correlation coefficient R_π can easily be observed by the method described above. Therefore, the polyconic chart method, used in map projections, was adopted as the method of organizing these observed values three-dimensionally. The values found as in Figure 8 were displayed in the manner of a contour map, as shown in Figure 9. That is, the directional distribution of R_π was plotted on spherical surfaces split at central angles of 30° along the circle of longitude.

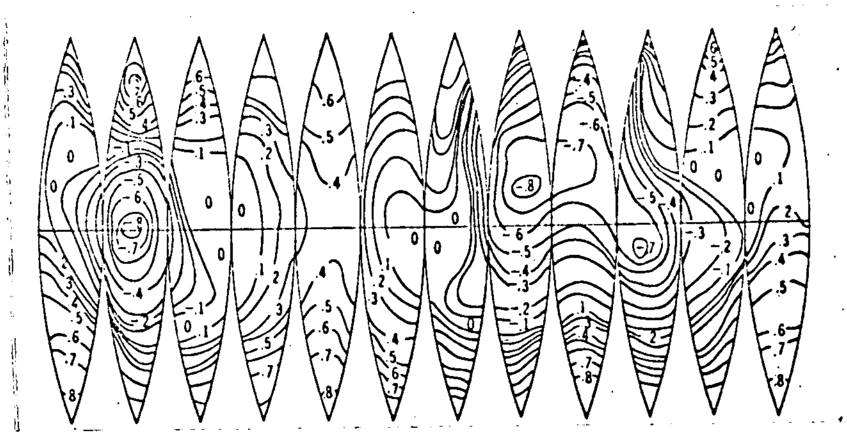


Figure 9. Directional distribution pattern obtained at the center of the chamber No. 2.

Test signal: 250 Hz, 1/3 octave band noise; number of diffusing plates: 0; area of the sound absorbing material: 16 m^2; (the values on contour lines indicate the distribution region of R_π)

The contour lines for the distribution regions of R_π are plotted in Figure 9 at intervals of 0.10, but it was ascertained that the necessary data will not be lost even if the width is expanded further for the purpose of performing sound field analysis. Therefore, also to simplify the calculations, it was decided to indicate the range of distribution, as shown in Table 1, with the values of R_π classified into eleven steps indexed from +10 to −10.

In the two reverberation chambers described in Table 2, the sound field conditions were varied in different ways using diffusing plates and sound absorbing materials; the directional distribution of R_π was measured for the respective sound fields, and many spherical diagrams were prepared. Hard board flat on both sides with a thickness of 5 mm and measurements of 90 cm × 180 cm was used as the diffusing plate, and glass wool board /138 with a density of 20 kg/m^3 and thickness of 50 mm was used as the sound absorbing material. The number of the diffusing plates and the area of the sound absorbing material were varied as shown in Table 3.

Typical examples of the spherical diagrams obtained by the measurements are shown in Figures 10, 11, 12, and in Figure 13. These are examples of measurements taken at a central frequency of 250 Hz.

TABLE 1. INDEX OF CORRELATION COEFFICIENT R_π

Index	Measured value of R_π
10	$1.0 \geqq R_\pi \geqq 0.85$
8	$0.85 > R_\pi \geqq 0.65$
6	$0.65 > R_\pi \geqq 0.45$
4	$0.45 > R_\pi \geqq 0.25$
2	$0.25 > R_\pi > 0.10$
0	$0.10 \geqq R_\pi \geqq -0.10$
−2	$-0.10 > R_\pi > -0.25$
−4	$-0.25 \geqq R_\pi > -0.45$
−6	$-0.45 \geqq R_\pi > -0.65$
−8	$-0.65 \geqq R_\pi > -0.85$
−10	$-0.85 \geqq R_\pi \geqq -1.0$

TABLE 2. DETAILS OF THE REVERBERATION CHAMBERS

	Chamber No. 1	Chamber No. 2
Volume	513 m^3	120 m^3
Surface area	382 m^2	148 m^2
Shape	Nonparallel walls	Rectangular parallelepiped

TABLE 3. VARIOUS CONDITIONS OF SOUND FIELD IN REVERBERATION CHAMBER FOR THE EXPERIMENTS

Chamber	The number of diffusing plates.	The area of the sound absorbing material.
No. 1	33, 15, 7, 0	35, 22, 10, 0 m^2
No. 2	16, 8, 4, 0	18, 13.5, 9, 4.5, 0 m^2

The diffusing plate: Hard insulation board, 900×1800×5 (mm)

The sound absorbing material: Glass-wool board 20 kg/m^3, 50 mm in thickness.

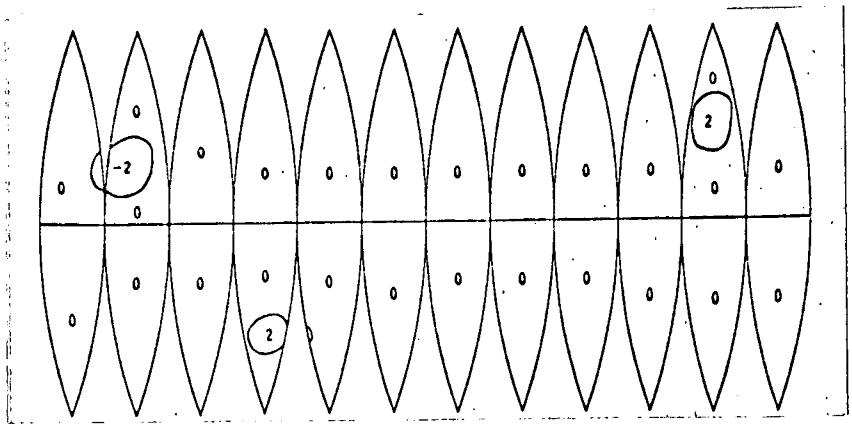


Figure 10. Directional distribution pattern obtained at the center of the chamber No. 1:

Test signal: 250 Hz, 1/3 octave band noise; number of diffusing plates: 0; area of the sound absorbing material: 10 m^2; (the values in contour map indicate the distribution region of R_π as in Table 1). In this case D_π = 97%

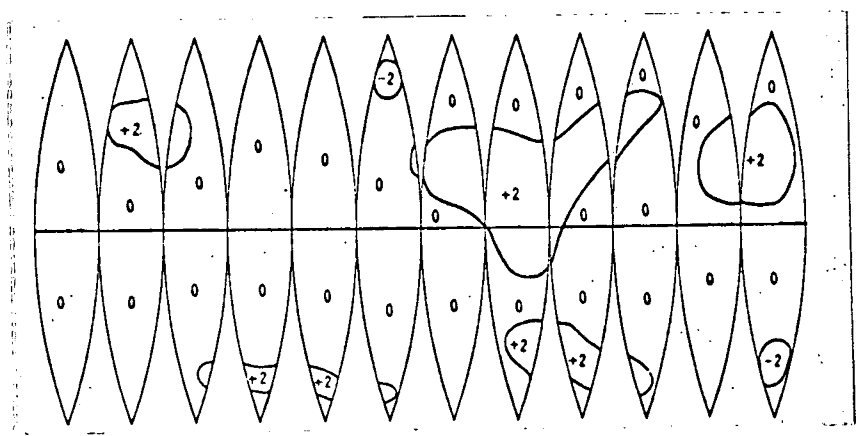


Figure 11. Directional distribution pattern obtained at the center of the chamber No. 1:

Test signal: 250 Hz, 1/3 octave band noise; number of diffusing plates: 15; area of the sound absorbing material: 22 m^2. In this case D_π = 70%

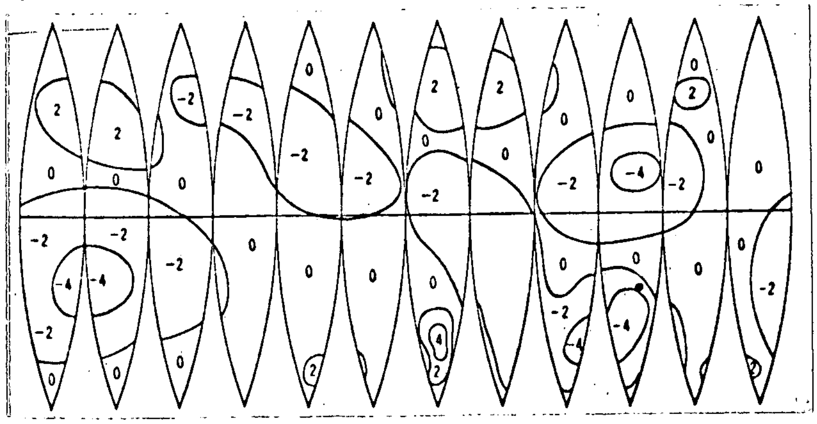


Figure 12. Directional distribution pattern obtained at the center of the chamber No. 1:

Test signal: 250 Hz, 1/3 octave band noise; number of diffusing plates: 15; area of the sound absorbing material: 35 m². In this case D_{π} = 50%

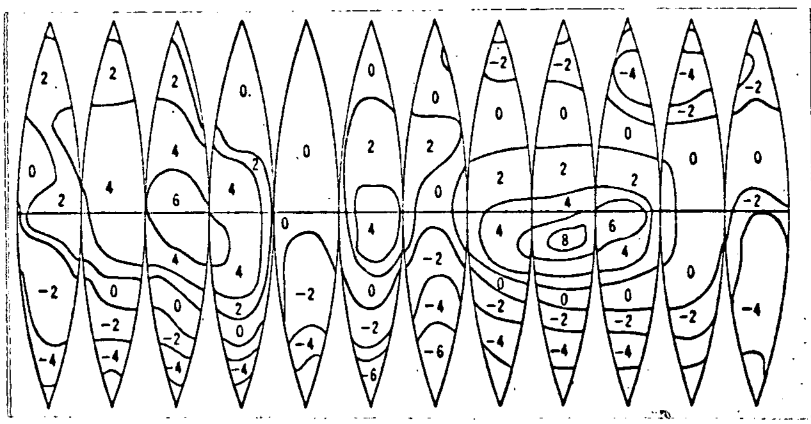


Figure 13. Directional distribution pattern obtained at the center of the chamber No. 2:

Test signal: 250 Hz, 1/3 octave band noise; number of diffusing plates: 0; area of sound absorbing material: 18 m². In this case D_{π} = 30%

Figure 10 shows the results when 10 m^2 of sound absorbing materials were installed on the floor of an irregularly shaped reverberation chamber. No diffusing plates were used. In this example, the zero range is predominant over almost the entire area of the spherical diagram. From this, it is possible to determine that $|R| \leq 0.1$ in all directions, and that the diffuseness of the sound field is extremely good.

Next, Figure 11 shows the results when the area of the sound absorbing materials was increased to 22 m^2 in the same reverberation chamber, and when 15 diffusing plates were suspended. Here also, the zero range is predominant over almost the entire area, although ranges other than zero appear in several places. That is, in this sound field, in several directions there is a direction in which $|R| > 0.1$, and there is a certain tendency towards the loss of diffuseness.

In Figure 12, this tendency appears even more conspicuous. These results were obtained by using 35 m^2 of sound absorbing material and 15 diffusing plates in the same reverberation chamber. There was a great decrease in the area occupied by the zero range, and the other ranges increased. The distribution /139 diagram also became more complex, and the diffuseness was rather poor.

Figure 13 shows the results obtained in a rectangular parallelepiped reverberation chamber using 18 m^2 of sound absorbing material and no diffusing plates. In this case, the zero range could be seen only in very limited sections, and it could be presumed from this distribution pattern that an axial mode was present in the sound field.

In this manner, various distribution patterns were observed, depending upon the sound field conditions. It was possible not only to judge the sound field structure from the state of distribution, but also to evaluate the diffuseness of the sound field.

Therefore, the following method of quantifying the state of distribution was established. Measurements were taken of R_π at 15° intervals (the total number of measuring points under condition 1 was 486) at a central angle on the entire spherical surface, centering around the fixed microphone. The value of D_π was defined as follows in terms of the area of the zero range:

$$\text{Diffusitivity index } D_\pi = \frac{[\text{Area occupied by zero range}]}{[\text{Total spherical surface area}]} \times 100\ (\%)$$

The D_π defined in this manner was calculated for the above-mentioned examples in Figures 10 - 13, and the results were inscribed in each of the figures. /140

The examples given here were found by installing the fixed microphone near the center of the reverberation chamber. However, even under the identical sound field conditions, it was found that the distribution seen on the spherical diagram would differ in various ways depending upon the measuring position. However, it was ascertained that great differences did not occur in index D_π, even when there were different states of distribution, with the exception of positions extremely close to the chamber walls, the sound absorbing surfaces, and the sound source speaker.

From this, it was concluded that the D_π found inside a reverberation chamber can be treated as the numerical value representing its sound field.

The D_π were experimentally calculated from the relevant spherical diagrams for each of the sound field conditions shown in Table 3. As a result, results ranging from 20% to 100% were obtained.

5. Relationship Between Index D_π and Measured Value of Reverberation Chamber Acoustic Absorptivity $\overline{\alpha}$

It is well known that differences will occur in the measured values of the reverberation chamber acoustic absorptivity based on Sabine's reverberation equation, which assumed a perfectly diffuse sound field, as a result of differences in the /141 diffuseness of the sound field. When the acoustic absorptivity does not coincide in different reverberation chambers even though the same materials are used, this is to be attributed in the final analysis to the problem of diffuseness [6].

Therefore, under the sound field conditions indicated in Table 3, the reverberation time was measured along with the measurement of the index D_π. The acoustic absorptivity $\overline{\alpha}$ of the glass wool used as the sound absorbing material was sought, and the relationship between D_π and $\overline{\alpha}$ was studied. This relationship is shown in Figure 14, where the measured value of the acoustic absorptivity $\overline{\alpha}$ is plotted on the ordinate, and the index D_π — on the abscissa. The results of measurements using 1/3 octave band noise of 250 Hz and 1,000 Hz were given as representative examples of the low sound zone and of the high sound zone, respectively.

The reverberation time for calculating the acoustic absorptivity $\bar{\alpha}$ was found in the following manner. Two to four measuring points, as necessary, were established inside the chamber, and 10 to 15 attenuation curves were measured for each point. The reverberation time was sought from the average value of these results. In sound fields in which $D_\pi < 40\%$, it was impossible to find the acoustic absorptivity because there were pronounced bends in the attenuation curves, because there were deviations at the same point, and because there were large differences at the receiving points.

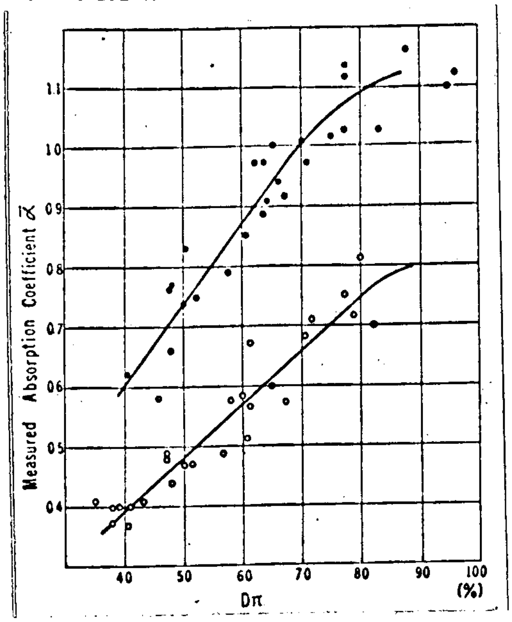


Figure 14. Relation between the index D_π and absorption coefficients $\bar{\alpha}$ measured for each condition in reverberation chambers. o — 250 Hz; ● — 1000 Hz, 1/3 octave band noise

In Figure 14, the acoustic absorptivity $\bar{\alpha}$ increased as the index D_π came closer to 100%. In the region where the value of D_π was higher than 75%, there was a tendency for $\bar{\alpha}$ to settle down more or less to a constant value. In sound fields where D_π was great, there were almost no bends in the attenuation curves, deviations at every measurement, and differences from one measuring point to another.

In these experiments, a series of evaluations were made on the basis of the index D_π covering a broad range of sound fields, such as a reverberation chamber with sound field conditions regarded as giving an extremely good diffuseness, a rectangular parallelepiped chamber with many problems in realizing a diffuse sound field, and sound fields equipped with large amounts of sound absorbing materials and having extremely poor diffuseness.

Here let us dwell on the effects of the diffusing plates which were used to change the sound field conditions. It is generally believed that the diffuseness of the sound field will increase when the number of diffusing plates increases. In Figures 15 and 16, the manner in which the measured values of

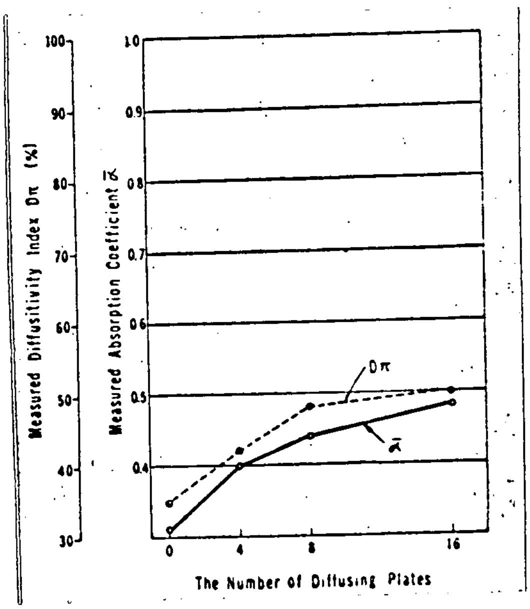


Figure 15. Relation between the number of diffusing plates and absorption coefficients $\bar{\alpha}$ and the index D_π measured in the reverberation chamber No. 2 for 250 Hz. The area of the sound absorbing material: 18 m^2

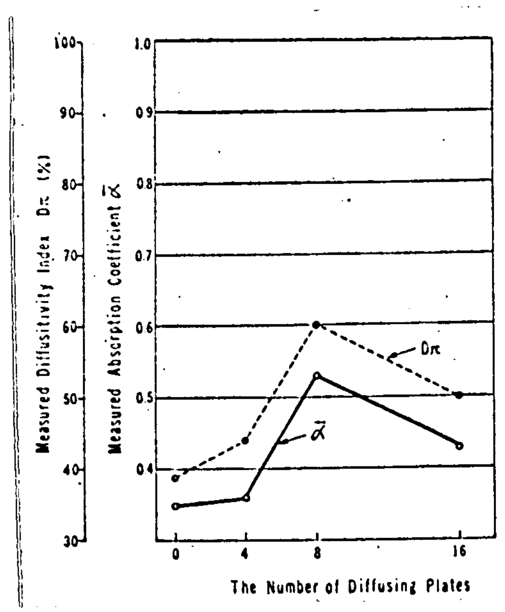


Figure 16. Relation between the number of diffusing plates and absorption coefficients $\bar{\alpha}$ and the index D_π measured in the reverberation chamber No. 2 for 250 Hz. The area of the sound absorbing material: 4.5 m^2

the acoustic absorptivity $\overline{\alpha}$ of sound absorbing materials having a constant area are affected by the number of diffusing plates is shown. Figure 15 gives the results of the experiments conducted in reverberation chamber No. 2 using 18 m^2 of sound absorbing material. The measured values of the acoustic absorptivity $\overline{\alpha}$ increased together with the number of diffusing plates, and it is assumed that the diffuseness of the sound field inside the reverberation chamber was improved by the diffusing plates. Figure 16 shows the results obtained in the same way using 4.5 m^2 of sound absorbing material inside the same reverberation chamber No. 2. In this case, the maximum value of $\overline{\alpha}$ was attained when there were eight diffusing plates, and there was a smaller value of $\overline{\alpha}$ when there were 16 diffusing plates. It was assumed that an increase in the number of diffusing plates does not /142 necessarily lead to an improvement of the sound field diffuseness inside a reverberation chamber, and that there is an effective number of diffusing plates. In Figures 15 and 16, the relationship between the index D_{π} and the number of diffusing plates was shown at the same time by dotted lines. The measured values of the acoustic absorptivity $\overline{\alpha}$ and the index D_{π} corresponded well. In this case it was concluded that, when the area of the sound absorbing material was 18 m^2, the best diffuseness of the sound field inside the reverberation chamber was obtained when there were 16 diffusing plates. When the area of the sound absorbing material was 4.5 m^2, the best diffuseness was obtained when there were eight diffusing plates.

As was clearly established, there is an extremely good correlation between the index D_{π} and the acoustic absorptivity $\overline{\alpha}$. This index is an effective yardstick for evaluating the diffuseness of the sound field inside a reverberation chamber.

In the past, the following difficulty arose in evaluating the degree of diffuseness of a sound field inside a reverberation chamber by means of the spatial correlation technique. Since it is difficult to observe the difference between the sin kr/kr and the correlation curves obtained by measurement in cases when there is relatively good diffusion, it was difficult to handle the data with reference to the sensitivity or the accuracy. The index D_π introduced here is effective also in dealing with this problem.

Our attention was focused on R_π, because the gradient of the correlation curve sin kr/kr reaches its maximum at $kr = \pi$. In this manner, it was found possible to establish even slight deviations from sin kr/kr.

Even though the spatial correlation coefficient observed by taking the distance r in only one direction should be sin kr/kr, this alone could not be a sufficient condition for judging the sound field to be a diffuse sound field; sin kr/kr was merely a necessary condition for a diffuse sound field. This was regarded as another difficulty. On the other hand, when index D_π is used, the spatial correlation coefficients are measured in all directions in the sound field, and three-dimensional observations are performed. Consequently, it is possible to establish accurately the properties of the sound field in which one is interested.

In view of these considerations, the use of the index D_π is an extremely effective method to attain the goal of evaluating and indicating the diffuseness of a sound field inside a reverberation chamber.

Conclusion

For the purpose of evaluating and indicating the diffuseness of the sound field inside a reverberation chamber, we measured the spatial correlation coefficients in all directions, derived the index D_π, and used it as the index of diffusion. Using two reverberation chambers (one irregularly shaped, another of a rectangular parallelepiped shape), we changed the sound field conditions by means of sound absorbing materials and diffusing plates and measured the index D_π under these various conditions. Further, under the various conditions, we measured the reverberation chamber acoustic absorptivity $\bar{\alpha}$ of the glass wool used as the sound absorbing material and sought the relationship between D_π and $\bar{\alpha}$. An extremely good correlation was observed between D_π and $\bar{\alpha}$, and the fact that it is valid to use D_π as an index of diffuseness was corroborated.

It was also determined that, if D_π is higher than 75% in a reverberation chamber, it has diffuse sound field conditions sufficient for measuring the reverberation chamber acoustic absorptivity.

In summing up the advantages of using the index D_π for evaluation, we can mention the following items:

1. By observing the correlation coefficient R_π in all directions, we can at the same time obtain data concerning the sound field structure.

2. As for the measuring frequency, there are in principle absolutely no restrictions, and handling is particularly easy in the low sound zone, which tended to be left out in the methods used in the past.

3. Since a small-size microphone-moving device is used in making the measurements, there is little fear that the sound field being investigated will be influenced by the equipment.

In view of the advantages mentioned above, the use of this method is extremely effective in evaluating and indicating the diffuseness of a sound field inside a reverberation chamber.

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